PB80-217730

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(U.S.) Corvallis Environmental Research Lab., OR

27 Jul 78

U.S. Department of Commerce
National Technical Information Service
NTIS

PB80-217730

EPA-600/J-78-174
JOURNAL ARTICLE

VOL. 14, NO. 6 WATER RESOURCES RESEARCH DECEMBER 1978

# The Impact of Broadly Applied Effluent Phosphorus Standards on Eutrophication Control

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The potential trophic benefits to lakes and reservoirs of a 1-mg/l and zero-discharge total phosphorus effluent standard for municipal sewage treatment plants were examined by using two phosphorus mass balance models. The analysis included 255 lakes and reservoirs receiving municipal sewage treatment plant effluents and located in the eastern half of the United States. [redacted]ater bodies, their significant tributaries, and contributing effluents were sampled during the U.S. [redacted]mental Protection Agency's National Eutrophication Survey. Improvement in trophic condition is defined as a predicted decrease of at least 25% in external phosphorus supply, which would cause the predicted in-lake total phosphorus concentration to (1) decrease from greater to less than 40 μg/l but remain above 20 μg/l, (2) decrease from above 20 μg/l to less than 20 μg/l, or (3) decrease from less than 20 μg/l to a lower concentration. The definition stated above being used, the two models indicate that 18–22% of the water bodies would benefit from a 1-mg/l effluent standard. If the requirement were zero phosphorus, 28% of the water bodies would benefit.

## INTRODUCTION

Accelerated eutrophication of lakes and reservoirs is caused by an increase in nutrients related to human activities. Such nutrients are contributed by both point and nonpoint sources. Municipal sewage treatment plants and some industrial effluents are point sources which represent concentrated and steady supplies of nutrients. Phosphorus from these sources is of special concern because concentrations are usually high and most of the phosphorus is in a form readily available for algae to use [*Gakstatter et al.*, 1978]. When it is necessary, phosphorus from point sources can be removed by special treatment processes.

The flow of nutrients from nonpoint sources is affected by precipitation and other factors and is therefore usually intermittent or irregular and often unpredictable. The magnitude of the nonpoint source inputs from any watershed is closely tied to land use activities which are related to topographical, geological, and meteorological conditions. Agriculture and urbanization are two types of land uses which usually contribute significant quantities of nutrients to surface waters [*Omernik*, 1976]. In general, nutrients from nonpoint sources are much more difficult to assess and control than those from point sources.

The two major nutrients of concern in accelerated eutrophication are phosphorus and nitrogen. Phosphorus is usually the element to be curtailed to control eutrophication because (1) most lakes were phosphorus limited prior to artificial enrichment and many could be made so again, (2) phosphorus can be readily removed from waste water by chemical processes, (3) there typically is no sizable natural phosphorus enrichment, although exceptions are known, and (4) efforts to make lakes nitrogen limited may be circumvented by atmospheric sources of nitrogen and nitrogen fixation by some blue-green algae and certain bacteria [*Bartsch*, 1972; *Schindler et al.*, 1973; *Porcella et al.*, 1974].

On the basis of these facts, several states have considered or implemented a blanket effluent standard for point sources of not more than 1 mg/l total phosphorus. While the intent of such regulation is commendable, our studies suggest that blanket nutrient requirements alone may have limited impact on eutrophication problems.

[redacted] 1978 by the American Geophysical Union.

Paper number 8W0844.
0043-1397/78/068W-0844$01.00

A question as to the efficacy of a single phosphous effluent standard resulted from studies on Shagawa Lake at Ely, Minnesota, conducted by the Corvallis Environmental Research Laboratory [*Malueg et al.*, 1975; *Larsen and Malueg*, 1976; *Larsen and Mercier*, 1976*b*]. Shagawa is a eutrophic lake with an infertile watershed; the major total phosphorus (P) input (80% of the total) has historically been contributed by Ely's municipal sewage. This provides a setting where a 1-mg/l effluent standard might be assumed adequate; however, analysis of the lake's response during a 4-year period of substantial reduction of phosphorus input by tertiary treatment showed that the expected results were not obtained.

The tertiary treatment plant at Ely consistently produced an effluent containing less than 0.05 mg/l of P from early 1973 to late 1977, reducing the external supply of P to the lake by 70–80% during that time. The decrease in P input, coupled with the hydraulic washout, decreased the lake P concentration by 40–45%, a reduction less than anticipated.

Although some improvements in Shagawa Lake quality are evident, the lake still exhibits characteristics of eutrophy, including noxious blooms of blue-green algae during the summer months. Had the total phosphorus in the effluent been 1 mg/l rather than 0.05 mg/l, the response of the lake would have been even less.

Because of the unexpected response of Shagawa Lake, we examined the potential effects of a blanket 1-mg/l effluent standard and a zero-discharge standard on the inputs of phosphorus and the predicted P concentrations and trophic conditions in a number of water bodies included in the National Eutrophication Survey (NES).

## METHODS

### *Models*

Several investigators have recently developed models for relating external phosphorus inputs, morphological characteristics of lakes, and resulting trophic conditions [*Dillon*, 1975; *Larsen and Mercier*, 1976*a*; *Vollenweider*, 1976]. These approaches are all based on total phosphorus mass balance considerations, i.e., that the phosphorus concentration [P] in a water body is a function of the rate of P inflow ($J$), the P outflow as affected by the water outflow ($Q$), and the P loss to the sediment ($R_{exp}$). The relationship can be expressed by the following steady state equation [*Rigler*, 1975]



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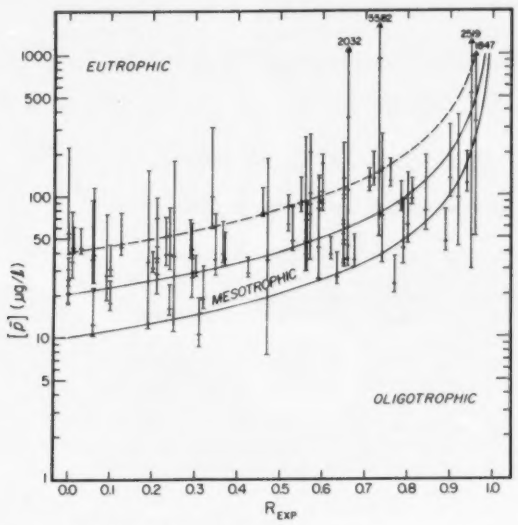


Fig. 1. Predicted changes (using the Larsen-Mercier model) in lake phosphorus concentrations and trophic conditions resulting from the implementation of 1-mg/l and zero-discharge effluent standards. The top, midmark, and bottom of each bar corresponds to the existing total phosphorus concentration, the 1-mg/l equivalent, and the zero-discharge level, respectively, for a given water body. Only those water bodies expected to improve in trophic conditions are illustrated.

$$[P]_\infty = (J/Q)(1 - R_{exp}) \quad (1)$$

The term $J/Q$ represents the average incoming concentration of phosphorus $[\bar{p}]$ and is equivalent to the quotient $Lp/(\rho_\omega \bar{z})$, where $Lp$ is the areal loading rate of total P from external sources ($g/m^2/yr$), $\rho_\omega$ is the number of water exchanges per year, and $\bar{z}$ is the mean lake depth in meters. The expression $R_{exp}$ represents the proportion of P lost to the sediments and can be estimated by 1 − (P outflow load/P inflow load). Details on the development of the mass balance relationships are given by *Dillon* [1975], *Rigler* [1975], *Larsen and Mercier* [1976*a*], and *Vollenweider* [1976].

*Larsen and Mercier*'s [1976*a*] graphical relationship (Figure 1), which is illustrated in this analysis, provides solutions to (1) corresponding to specific values of $[\bar{p}]$ and $R_{exp}$. The upper solid curve in Figure 1 represents an in-lake phosphorus concentration of 20 μg/l, above which eutrophic conditions would be expected to predominate. The lower solid curve represents an in-lake concentration of 10 μg/l, below which oligotrophic conditions would be expected [*Dillon*, 1975].

Since trophic condition is a continuum, it is obvious that the 10- and 20-μg/l curves in Figure 1 do not represent a series of absolute values which sharply separate one trophic condition from another. For example, a lake which plots a short vertical distance above the 20-μg/l curve could exhibit reasonably good water quality. Thus for the purpose of evaluating the effect of effluent standards, a conservative in-lake phosphorus concentration of 40 μg/l was selected to delineate acceptable and nonacceptable trophic conditions. This selection is justifiable in that *Bachmann and Jones* [1974] have shown that secchi depth transparencies are relatively insensitive to changes in total phosphorus concentrations above 40 μg/l. An in-lake concentration of 40 μg/l is represented by the dashed line in Figure 1.

It is also evident from Figure 1 that a relatively small percent change in total phosphorus concentration would not result in a significant vertical displacement on the graph, since the scale is logarithmic. For this reason a 25% reduction in the average incoming total phosphorus concentration $[\bar{p}]$ was chosen as the minimum which would be expected to exert a signficant influence on trophic condition.

The *Larsen and Mercier* [1976*a*] approach was selected for primary use in this analysis because it reflected the most logical and direct relationship between total phosphorus $[\bar{p}]$ delivered to a water body and the ability of that water body to assimilate phosphorus ($R_{exp}$). However, either the *Dillon* [1975] or the *Vollenweider* [1976] relationship would have served adequately. The Dillon model would have given results identical to those of the Larsen and Mercier model, since the same parameters are incorporated in only a slightly different manner of presentation. The Vollenweider relationship uses mean hydraulic retention time rather than phosphorus retention time and therefore gives slightly different results. For purposes of comparison, our data were also analyzed by using the Vollenweider relationship, and while the results are not graphically illustrated, they are summarized in this report.

### *The Data Base*

Phosphorus inputs from point and nonpoint sources, morphometric data, and trophic state data were obtained through the National Eutrophication Survey which was conducted from 1972 to 1975 by the U.S. Environmental Protection Agency's Environmental Research Laboratory at Corvallis, Oregon, and Environmental Monitoring and Support Laboratory at Las Vegas, Nevada. Because the remainder of the data have not yet been computerized, only lakes and reservoirs from 27 states, extending from the east coast to the Mississippi River, are included in this analysis.

Total phosphorus inputs to and outputs from each water body were based on a monthly sampling of the major tributaries and outlets for 1 year. Estimates of phosphorus inputs from precipitation, septic tanks, and the unsampled portion of each lake's drainage area were included in the total phosphorus input. Most municipal waste water treatment plants impacting each water body were sampled monthly for 1 year to determine their contributions. For plants which were not sampled, phosphorus inputs were based on the population served. The nonpoint source phosphorus contribution was determined by the difference between known point source inputs and the total input. Details of sampling and analytical procedures are provided in NES working papers [*U.S. Environmental Protection Agency*, 1974, 1975].

### *Simulation of the 1-mg/l Phosphorus Effluent and Zero-Discharge Standards*

Simulating the reduction of point source effluent phosphorus from existing levels to 1 mg/l for each treatment plant was not practical because of the number of facilities involved. Instead we assumed that each facility discharged an effluent of average characteristics. The NES data for 709 municipal waste water treatment plants, representing a variety of treatment types, indicated that the median effluent concentration was 6.1-mg/l total phosphorus [*Gakstatter et al.*, 1978]. The 1-mg/l effluent restriction therefore corresponds to an average 84% reduction in effluent total phosphorus. Thus to simulate the 1-mg/l effluent standard, total phosphorus loading from point sources was reduced by 84%. This approach is likely to produce errors in the estimated loading for an individual water body, but the errors should cancel for a large number of water bodies and provide an acceptable overall analysis.

BIBLIOGRAPHIC INFORMATION

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PERFORMER: Corvallis Environmental Research Lab., OR.
EPA-600/J-78-174

Pub. in Water Resources Research, v14 n6 p1155-1158 Dec 78.

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KEYWORDS: *Phosphorus, *Water pollution, *Lakes, *Reservoirs, *Eutrophication.

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PRICE CODE: PC A02/MF A01

A second analysis of the data was made assuming zero discharge of nutrients from the same point sources. In this case the estimated phosphorus load from each facility was deleted, and the hypothetical impact on each water body was assessed by using the Larsen-Mercier and Vollenweider relationships.

## RESULTS

Figure 1, which represents the Larsen-Mercier approach, summarizes the changes expected in water bodies where a significant response could be predicted using the selection criteria described earlier. The top of each bar in Figure 1 represents the in-lake phosphorus level before any effluent restriction. The line across each bar represents the predicted in-lake phosphorus level corresponding to a 1-mg/l effluent standard and the bottom of each bar represents that level corresponding to a zero phosphorus discharge standard. Fifteen of the 255 water bodies analyzed could be expected to change from eutrophic to a lower trophic condition (mesotrophic or oligotrophic) owing to implementation of the 1-mg/l phosphorus effluent standard. In addition, in-lake phosphorus concentrations of 31 of the water bodies would be reduced to less than 40 $\mu$g/l; therefore they would probably exhibit improved trophic conditions, such as increased secchi depth, but would remain eutrophic. Nine of the water bodies which were initially oligotrophic or mesotrophic would experience phosphorus loading reductions which would contribute to maintaining their desirable trophic condition. In summary, 22% (55/255) of the water bodies could be expected to benefit visibly from the phosphorus effluent standard.

Similar predictions result if the Vollenweider relationship is used: 12 water bodies would change from eutrophic to a lower trophic condition, in-lake P concentrations in 28 water bodies would be reduced to less than 40 $\mu$g/l, and seven water bodies which were already oligotrophic or mesotrophic would experience phosphorus loading reductions. In total, 18% (47/255) of the water bodies would be expected to benefit.

According to the Larsen-Mercier approach (Figure 1), if a zero phosphorus discharge policy were imposed, 34 of the water bodies would be expected to change from eutrophic to a lower trophic condition, 27 would remain eutrophic but would be expected to improve markedly, and 10 oligotrophic or mesotrophic water bodies would experience phosphorus reductions. In total, 28% of the 255 water bodies would benefit.

Again, similar predictions result from the Vollenweider analysis, which predicts that 27% of the water bodies would benefit from a zero-discharge policy.

## DISCUSSION

Our analysis suggests that the nonselective implementation of a total phosphorus effluent standard applied to the extreme (zero phosphorus discharge) would appreciably benefit about 28% of the water bodies included in the NES which receive municipal sewage effluents.

The general models that we have used in this analysis, both of which are based on (1), make two major assumptions which would conservatively bias the estimate of benefit. Those assumptions are that phosphorus inputs to water bodies are uniform throughout the year and that the water bodies are completely mixed and in P equilibrium. In reality, effluents may be much more significant during the algal growing season, when stream flows are low and nonpoint source inputs are minimal. These inputs may also cause localized eutrophication problems in the vicinity of discharge because mixing throughout the water body is rarely complete. Both of these situations might be improved through the application of effluent standards, even though the general models might not predict improvement.

Another factor, which neither of the models considers, is the effect of reducing external phosphorus supplies on the frequency of nuisance algal blooms even though a water body may remain eutrophic. We have attempted to account for this, in part, by assuming that in-lake phosphorus concentrations reduced to less than 40 $\mu$g/l would result in some visible improvement, although our assumption is based on changes in water transparency. If, in fact, the frequency of nuisance algal blooms was reduced when in-lake phosphorus concentrations were reduced, but remained above 40 $\mu$g/l, more water bodies would benefit than our analysis has demonstrated.

The argument could also be made that our method of predicting benefit is overestimating reality. For example, phosphorus return from lake sediments could slow the trophic improvement following the reduction of external phosphorus inputs, as it apparently has in Shagawa Lake [*Larsen et al.*, 1975], even though the predicted trophic condition might eventually be reached. Attainment of the improved trophic condition, however, might be expedited by applying hypolimnetic aeration or some other measure designed to reduce solubilization of sediment phosphorus.

The difficulty with any fixed-level effluent phosphorus criterion, applied within political boundaries, is that the unique characteristics which determine the response of each water body are not accounted for. These characteristics include morphometry, hydraulic retention time, percent of the external phosphorus supply from point sources relative to that from nonpoint sources, natural background phosphorus levels related to the geology and climate of the watershed, recycled nutrients from bottom sediments, and whether or not phosphorus is the algal growth-limiting element.

In addition to having a limited impact, a blanket phosphorus effluent criterion may lead to a false sense of security concerning eutrophication control, when in fact additional measures such as nonpoint source phosphorus controls may be needed to slow accelerated eutrophication for specific water bodies. In a recent analysis of the effect of a 1-mg/l effluent standard in the Great Lakes Basin, *Chapra and Robertson* [1977] predicted water quality improvements over much of the Great Lakes but stated that Lower Green Bay, Saginaw Bay, and western Lake Erie would additionally require nonpoint source controls before significant trophic improvements would occur.

## CONCLUSIONS

The fixed-level effluent phosphorus criterion applied within political boundaries is one possible approach to accelerated eutrophication control. It is an approach which does not account for the unique characteristics of each lake or reservoir within the area of concern; therefore the results from its application will be limited. Our analysis suggests that the implementation of a 1-mg/l total phosphorus requirement for municipal effluent would favorably impact 22% of the water bodies receiving municipal effluents and that a zero phosphorus requirement would favorably impact 28%. The remaining water bodies would not respond because of the dominance of other external sources of phosphorus, e.g., nonpoint relative to point source supplies.

Optimal control of accelerated eutrophication requires that the characteristics of each water body and its nutrient sources be evaluated (see *Dillon and Rigler* [1975] for an examination

of this approach). Following evaluation, a reasonable prediction could be made of the feasibility, the reduction required, and potential benefits of nutrient controls.

*Acknowledgments.* We thank David P. Larsen, Kenneth W. Malueg, and Charles F. Powers for their review and helpful suggestions and Beverley P. Bowman for typing the manuscript.

## REFERENCES

Bachmann, R. W., and J. R. Jones, Phosphorus inputs and algal blooms in lakes, *Iowa State J. Res., 49,* 155–160, 1974.

Bartsch, A. F., Role of phosphorus in eutrophication, *Rep. EPA-R3-72-001,* U.S. Environ. Prot. Agency, Corvallis, Ore., 1972.

Chapra, S. C., and A. Robertson, Great Lakes eutrophication: The effect of point source control of total phosphorus, *Science, 196,* 1448–1450, 1977.

Dillon, P. J., The phosphorus budget of Cameron Lake, Ontario: The importance of flushing rate to the degree of eutrophy of lakes, *Limnol. Oceanogr., 20,* 28–39, 1975.

Dillon, P. J., and F. H. Rigler, A simple method for predicting the capacity of a lake for development based on lake trophic status, *J. Fish. Res. Bd. Can., 32,* 1519–1531, 1975.

Gakstatter, J. H., M. O. Allum, S. E. Dominguez, and M. R. Crouse, A survey of phosphorus and nitrogen levels in treated municipal wastewater, *J. Water Pollut. Contr. Fed., 50,* 718–722, 1978.

Larsen, D. P., and K. W. Malueg, Limnology of Shagawa Lake, Minnesota, prior to reduction of phosphorus loading, *Hydrobiologia, 50,* 117–189, 1976.

Larsen, D. P., and H. T. Mercier, Phosphorus retention capacity of lakes, *J. Fish. Res. Bd. Can., 33,* 1742–1750, 1976*a*.

Larsen, D. P., and H. T. Mercier, Shagawa Lake recovery characteristics as depicted by predictive modeling, *Rep. EPA-600/3-76-079,* pp. 114–137, U.S. Environ. Prot. Agency, Corvallis, Ore., 1976*b*.

Larsen, D. P., K. W. Malueg, D. W. Schults, and R. M. Brice, Response of eutrophic Shagawa Lake, Minnesota, U.S.A., to point-source, phosphorus reduction, *Verh. Int. Ver. Theor. Angew. Limnol., 19,* 884–892, 1975.

Malueg, K. W., D. P. Larsen, D. W. Schults, and H. T. Mercier, A six-year water, phosphorus, and nitrogen budget for Shagawa Lake, Minnesota, *J. Environ. Qual., 4,* 236–242, 1975.

Omernik, J. A., The influence of land use on stream nutrient levels, *Rep. EPA-600/3-76-014,* U.S. Environ. Prot. Agency, Corvallis, Ore., 1976.

Porcella, D. B., et al., Comprehensive management of phosphorus water pollution, *Rep. EPA-600/5-74-010,* U.S. Environ. Prot. Agency, Washington, D. C., 1974.

Rigler, F. H., Nutrient kinetics and the new typology, *Verh. Int. Ver. Theor. Angew. Limnol., 19,* 197–210, 1975.

Schindler, D. W., H. Kling, R. V. Schmidt, J. Prokopowich, V. E. Frost, R. A. Reid, and M. Capel, Eutrophication of lake 227 by addition of phosphate and nitrate: The second, third, and fourth years of enrichment, 1970, 1971, and 1972, *J. Fish. Res. Bd. Can., 30,* 1415–1440, 1973.

U.S. Environmental Protection Agency, National Eutrophication Survey methods for lake samples in 1972, *Work Pap. 1,* Corvallis, Ore., 1974.

U.S. Environmental Protection Agency, National Eutrophication Survey methods 1973–1976, *Work. Pap. 175,* Corvallis, Ore., 1975.

Vollenweider, R. A., Advances in defining control loading levels for phosphorus in lake eutrophication, *Mem. Ist. Ital. Idrobiol., 33,* 53–83, 1976.

(Received July 14, 1977;
revised July 10, 1978;
accepted July 27, 1978.)